FRIENDLY WORKERS of the SOIL

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Ten Lessons

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A study of soil-bacteria, in relation to practical farming

CONTENTS

2-8-1921

FOREWORD

The purpose of this booklet is to tell in a clear and concise manner the story of the bacterial life of the soil, particularly in its relation to practical farming.

LESSON I

AN INVISIBLE WORLD

Bacteria Defined

Bacteria are minute living organisms, visible only under the eye of a powerful microscope, and so simple of structure that their classification as plants rather than animals long remained uncertain. A particle of matter may contain many thousands of bacteria. Water, earth and air are teeming with this unseen life in its infinite variety. Some bacteria are harmful to higher forms of life; they are the disease producers. Others are the busy workmen of nature's bounty, enriching the earth and making possible life for plants and animals.

Existence of Bacteria First Discovered in 1675

Many of the results of bacterial activity, such as putrefaction and fermentation, have been familiar to man since the beginning of time, but the existence of bacteria themselves became known only near the end of the seventeenth cen-

tury. Their discovery was made possible by the perfecting of the compound microscope which made visible to man a new world of plant and animal life. Since then the petrified cells of bacteria have been discovered in the rocks, making clear that they existed before the age of man, and in forms not very dissimilar from those of today. They were first definitely recognized in 1675 by a Dutch scientist, Leeuwenhoek, who called them "animalcules."

Means of Recognizing Bacteria

The different forms of bacterial life are recognized not only by their appearance under the microscope, but also by the various chemical changes they produce in the matter in which they live. They are both destroyers and builders, transforming plant and animal matter into new substances.

LESSON II

FIGHTING THE DESTROYERS

Medical Science Enriched by Study of Bacteria

The study of disease-producing bacteria is of absorbing interest and has largely made possible our present-day achievements in medical science. Antiseptic surgery by which amazing operations are performed was the result of this study. Today no surgeon would think of touching the human body with a

knife without first sterilizing it, that is, destroying such bacterial life as might carry infection to the wound. Our effective control of contagious diseases was made possible by the same study. Vaccination for smallpox and inoculation for typhoid, for example, have incalculably diminished the ravages of these diseases.

Three Types of Bacteria

It will be of interest to note the appearance of bacteria as seen under the microscope. There are three principal types which have been described as reminding one of billiard balls, lead pencils and corkscrews. The first type is seen as chains or clusters of balls, the second as elongated cells often joined to each other at the ends, and the third frequently as twisted threads. The spherical bacteria average about one twenty-five thousandth of an inch in diameter, while the others may be as much as one thousandth of an inch in length. Some bacteria move about in a liquid medium; while others appear to be motionless.

Method of Growth

Bacteria propagate themselves by splitting into halves, thus forming two distinct organisms which again have the power to divide. As this process may be completed in as short a time as half an hour, it will be seen that bacterial life,

under favorable circumstances, may increase with amazing rapidity.

Conditions Necessary For Reproduction

The limitations of increase are provided by two factors. First, the exhaustion of food supply, and, second, the accumulation in the medium surrounding the bacteria of injurious substances, as, for example, the excretions of the bacteria themselves.

LESSON III

BACTERIAL ARMOR

Spores and Their Relation To Bacteria

As a means of preserving life under adverse conditions, many bacteria have the power of producing spores. The spores have been called "bacterial eggs," but the use of the phrase must not lead to a misunderstanding. The spore is a bacterial body changed into a more resistant form by being surrounded by a tough cell wall. The spore may retain life amid uncongenial surroundings for a long period, even years. When brought into favorable conditions it bursts open, producing a new bacterial cell which multiplies in the usual manner.

In pasteurizing liquids, as milk, sufficient heat is used to destroy bacterial cells but not the spores. Sterilization

implies the destruction of cells and spores alike.

A condition which affects, favorably or unfavorably, the life and growth of bacteria is temperature. Active life, in some species, may be found within the range of only a few degrees, the bacteria protecting themselves against unfavorable heat or cold by spore formation. Some spores resist extreme heat, while others may be frozen in ice and resume activity when the ice is melted.

Aids to Bacterial Growth

An amount of water also is necessary. In the case of bacteria living in humus in the soil, activity practically ceases when there is only two or three per cent of moisture, and is most noticeable with twenty-five or thirty per cent. In vegetable or animal substances more water is necessary.

Some bacteria require oxygen taken from the air, while for others the presence of air is death.

Sunlight, on the whole, is destructive to the bacterial world. Sunlight is nature's germicide.

LESSON IV

FRIENDLY HELPERS ON THE FARM

The practical farmer who reads this booklet may naturally question what

Why a Knowledge of Bacteriology?

the subject of bacteriology has to do with his gaining a living from the soil. It has much to do with it. The study of bacteriology gives us a new insight into the reasons for soil fertility and aids in a very practical way in increasing the producing power of our fields.

Relation of Bacteria To Soil Fertility

The soil of the field is the medium in which lives a countless variety of bacterial life, and upon this life depends greatly the transformation of the soil into food for our growing crops. Our understanding of the bacteria aids us in maintaining and building up the soil capital of the farm.

In a number of industries, such as treating milk and milk products, canning, pickling of fish, tanning of leather and curing of tobacco, the science of bacteriology has been found of inestimable value. Agriculture can profit by it no less.

Renovating Power of Bacteria in the Soil

The bacteria of the soil are nature's scavengers, extracting from the humus, that is, the decaying bodies of plants and animals, such elements as carbon, hydrogen, nitrogen and sulphur, and setting them free as food elements for another generation of plant and animal life. Without their

activity, dead matter would accumulate and life would fail for want of food.

The number of these friendly workers in the soil depends upon several conditions. As a degree of moisture is necessary for their development, they are found to increase after rain. Warmth, too, is necessary. Spores lying dormant in frozen earth must wait for the sun of springtime to rouse them to activity. In the warm and moist months of early summer they work most rapidly.

LESSON V

THE FOOD OF PLANTS

Value of Carbon To the Plant

Let us see more clearly how this transformation of dead material into plant food takes place. One necessary plant-food element is carbon. This enters largely into the construction of the tissues. It is said that nearly a ton of carbon each year is required as food by an acre of beech forest. The fibre of rye straw contains forty per cent of carbon. This food is obtained by the green plant from the air in the form of carbon dioxide gas which it decomposes, building the carbon in its tissues. It is evident that this gas must be constantly renewed in the

air or the plant food will be exhausted and the world of vegetation will starve.

There are several ways in which this renewal is accomplished. Carbon is set free in the burning of wood and coal and in the breath of animals. More important, however, is the liberation of carbon dioxide gas in the decay of organic matter.

Sources From Which Carbon Is Obtained

In this process of decay, as we have seen, the bacteria have an essential part. The bacteria are the tireless destroyers of dead vegetable organisms. Stubble, roots, leaves, twigs and all the discarded material of field and forest are transformed by them, and their food elements set free.

LESSON VI

CONDITIONS OF BACTERIAL LIFE

It will now be evident that of most practical interest to the farmer is the maintenance of the bacterial life of his fields. He will need to understand the conditions upon which depend the number and activity of these friendly workers of the soil. First among these conditions, as we have said, is the presence of moisture. Protracted drouth is a hindrance to bacterial life. Their number and activity naturally increase after rain.

Maintaining Bacterial Life In the Soil

Bacteria which require air for their nourishment thrive best in sandy soil which allows air penetration. Those which cannot live in air are naturally found in clay.

By Crop Rotation

Crops grown on the soil also affect materially the nature and number of bacteria in it. A primary reason for crop rotation is to create favorable conditions for a large variety of bacteria, thus insuring the proper transformation of humus into plant food.

By Fertilizers and Manures

A factor of great importance in bacterial development is the application of fertilizers and manures. Barnyard manure, for example, being rich in bacteria, greatly increases their number in the soil. The application of lime also has effects upon bacterial life which are long persistent.

By Increasing Humus

Humus, composed of decaying vegetable and animal organisms, is, in general, the food of the soil bacteria. There is, however, one important exception, that of certain nitrogen-fixing bacteria, which are to be spoken of later. The number of bacteria is affected not only by the amount of this humus food, but also by its character. The raw humus of swamps and peat lands, acid in character, is a poor food,

and for the proper increase of bacterial life such lands must be drained and limed.

Relation of Soil To Bacterial Life

It is evident that the nature of the soil will affect greatly the bacterial life in it. Consider the field of sand or sandy loam. Persistent application of fertilizers seems to have no lasting effect. The soil remains light and the crops thin. This is due largely to the too rapid transformation of the humus under the attacks of an intense bacterial life.

Sandy Loam

Little water is retained in this soil and its looseness permits a rather free circulation of air. Under these conditions certain air-loving bacterial species multiply greatly, and the decay of the humus becomes a sort of slow burning and it is too rapidly exhausted.

It is evident that such land, to be cropped profitably, must have large and repeated applications of humus-forming material. Green-manuring also is practicable, as the food elements of decaying vegetation are rapidly liberated.

Clay

Again, here is a field of clay, its soil fine-grained and compact. There is little space for the circulation of air. Bacterial life does not thrive under these conditions and the disinte-

gration of humus takes place too slowly.

Swamp Land

In the case of water-logged soil and swamp land the presence of excessive moisture accomplishes the same result. Here organic matter tends to putrefaction rather than decomposition into plant food. But a small portion of the humus becomes carbon dioxide. Part of it escapes from the soil as marsh-gas, while some of it remains as humic acids, making the land sour. For the proper development of bacterial life in such land, drainage and liming are necessary.

LESSON VII

THE SOIL FACTORY

Bacteria—A Nitrifying Agent

Let us now consider those forms of bacterial life of most practical and vital interest to the farmer. Among the essential plant-food elements is nitrogen. This element constitutes about four-fifths of the atmosphere surrounding the earth and permeating the soil. Most of the nitrogen plant-food is derived from the disintegration of humus, which is broken down by the bacteria of the soil and made available for the plant.

This process must be noted with some care. The food of plants, as of

How Plants Assimilate Food

animals, is composed of carbohydrates, fats and proteins. Plants do not feed directly upon soil-humus or even upon the elements of which soil-humus is composed. Unlike animals, the plant has power within itself to change elements into food, but the humus must first be broken down and the elements set free. This is the work of one group of friendly bacteria. The breaking down of the humus into the nitrogen food element is a complex matter, consisting of three distinct operations, and for these three operations at least three distinct sorts of soil bacteria are necessary. No one species is competent to do the entire work.

The Soil—A Plant Food Factory

We may liken the soil to a factory in which humus is manufactured into the plant-food element nitrogen. In this factory the raw material passes successively through three operations at the hands of three sets of workmen. These workmen are specialists in their own craft and those of one trade cannot do the work of the others.

The first process is the transforming of the raw material into ammonia.

Plant Food First Changed To Ammonia

There are many kinds of bacteria that can do this. This transformation is a chemical change produced in the process of digestion. While bacteria must digest their food, like animals, they do this outside the body cavity. As the digestive organs of the animal produce pepsin, so the bacteria may produce chemical ferments called enzymes which pass out through the cell wall, causing a chemical change in such protein food substances as may be adjacent. This digested food is then assimilated by the organism. In the digestive process ammonia is produced.

Nitrite and Nitrate

The second operation in food-element production performed by a different set of workmen, is the transforming of ammonia into nitrite. The difference between a nitrite and a nitrate is that the nitrate contains three parts of oxygen to one of nitrogen, and the nitrite only two. The third operation effected by a third set of workmen is the transformation of nitrite into nitrate. This is an element which the plant can change into its own food.

The bacteria necessary to these three operations are called the nitrifying

The Difference Between Nitrogen-freeing and Nitrogen-fixing Bacteria

bacteria. We need to carefully distinguish them from the ***nitrogen-fixing*** bacteria to be considered later. The nitrifying bacteria are busy workmen in nature's factory, but they use only the material at hand. The nitrogen-fixers are the wealth accumulators of the soil store-house, importing nitrogen from the air and enriching the earth with their merchandise. They are thus indispensable, and the study of their habits and the conditions under which they thrive is of great practical use to the farmer.

LESSON VIII

THE WASTE OF NITROGEN

Chief Means of Waste:
1. Vaporization
2. Leaching

Not all of the nitrogen produced by the bacteria becomes nourishment for the crop growing in the soil. Much of it is wasted and one problem of practical farming is the prevention of this waste. There are two ways in which waste takes place. One is the setting free of gaseous nitrogen to return to the atmosphere. This happens when, as in sandy soil, the humus transformation takes place too rapidly. The other notable means of waste is the

leaching out of nitrates in soluble form. In this case excessive rainfall washes the nitrates into the subsoil where they cannot be reached by the roots of surface-growing plants.

Waste Through Unfriendly Bacteria

Of primary importance is the character of the soil bacteria. It has been seen that certain species are necessary to the formation of nitrates, and upon the number and strength of these species the amount of the available nitrogen food-element largely depends. Other species make use of considerable quantities of the nitrates in the building of their own bodies, thus becoming actual competitors of the plants for the nitrogen of the soil. Still other species return nitrogen to the air in a gaseous form, thus working to the detriment of the crop. ***The importance of the presence in the soil not only of bacteria, but of the right kind of bacteria, is thus evident.***

LESSON IX

PUTTING PLANT FOOD INTO THE SOIL

Methods of Adding Nitrogen to the Soil

We come now to the consideration of practical methods by which the farmer can add to the nitrogen food value of the soil.

1. Direct Application

The first is the direct application to the land of nitrogen salts, such as nitrate of soda. However, this method is costly, unnecessary and usually inadvisable, except for very poor land or in intensive gardening.

2. Barnyard Manure

The second method is that of returning humus to the soil in the form of barnyard manure. The farmer thus conserves and uses a part of the humus-forming material of his crops. The value and necessity of this sort of fertilization is so well understood as to require no emphasis. However, this is to be said. The farmer cannot possibly hope to return to the land by this method alone as much plant-food material as has been removed by the growing crop. It is asserted that, on tight floors, 75 per cent of the fertilizing elements contained in feed may be recovered in manure. It is evident that 25 per cent must be lost to the soil. Be-

sides, there is inevitably some loss by leaching after the manure has been applied to the soil. ***Every product sold off the farm, whether in grain or live stock, means the removal of soil value. Manuring must be supplemented by some other means of enriching the land.***

3. By Drawing Nitrogen From the Air

The third method is one of simple co-operation with nature. It is the process of drawing nitrogen from the air to supply the soil. This is accomplished by the growing of legume crops, a familiar and generally used method.

How Legumes Add Nitrogen to the Soil

Among the legumes used for this purpose are the clovers, alfalfas, soy beans and cow peas. The peculiar value of clover in enriching the soil was well understood in the eighteenth century, but the reason for this value was a subject of speculation. It was a popular supposition that the deeply penetrating roots brought food from the subsoil and made it available in surface humus for succeeding crops.

The problem began to work toward its right solution in 1886, when it was observed that peas grown in artificial soil, containing no nitrogen compounds, usually died after the nitrogen of the

seed itself was exhausted and that those which survived to maturity invariably had developed nodules on the roots. Nodules are tubercle-like swellings, rather small on clover and larger on other legumes. It had been previously found that the root nodules were formed and occupied by colonies of bacteria.

Function of Nodules

These discoveries led to the conclusion that the bacteria of the root ***nodules have the power of acquiring the free nitrogen of the air contained in the soil and transforming it into food material for the plant.*** They penetrate the root hairs from the soil, and, finding a favorable place for development, pass from one cell of the plant to another, reaching the interior of the root. The root then enlarges and the nodule is formed.

The plant supplies the bacteria with sugar and with other needed food-substances and in return the bacteria make the nitrogen of the air available as a food element for the plant. The legumes are thus able, with the assistance of the bacteria, to derive nitrogen from the air, a peculiarity possessed by no other plant family. This nitrogen is eventually given by the plant to the soil. It is estimated that the quantity of nitrogen thus utilized would be

worth from sixteen to thirty dollars per acre if bought in the form of nitrogen salts.

Function of Symbiotic Bacteria

The bacteria which perform this operation are nitrogen-fixing bacteria. We have already pointed out their distinction from nitrifying bacteria, which only transform the material which they have already found waiting their labor in the soil factory. The bacteria associated with the legumes, called the symbiotic bacteria, are not the only bacteria of the soil which have the power of taking nitrogen from the air, but, for the purposes of practical farming, they are the ones requiring special consideration.

LESSON X

THE INDISPENSABLE CONDITION

The Necessity of Nodules on the Roots of Legumes

In the growing of legume crops such as clover, alfalfa, peas or beans for the fertilization of the land, one fact is of prime importance. ***The legume bacteria must be in the soil.*** Unless there are nodules on the roots, the crop has no fertilizing power. It does not enrich and may actually impoverish the soil. No nodules will be borne on the roots unless

the particular species of nitrogen-fixing bacteria adapted to the particular plant is in the soil. There is no one species of bacteria capable of working with all the leguminous plants. The clover bacteria do not work with soy beans. The bacteria of sweet clover and alfalfa do not form nodules on the roots of peas.

Classification of Legumes

Among agricultural plants there are recognized six groups of legumes, each depending upon a distinct species of bacteria. These groups are (1) Alfalfa, Sweet Clover and Burr Clover, (2) the true clovers, Red, Alsike, White Dutch and Crimson, (3) Soy Bean, (4) Cow Pea, Jap Clover, Lima Bean and Velvet Bean, (5) Garden and Field Bean, (6) Garden and Field Pea, and Vetch.

Need of Proper Bacteria

Even if grown not as a fertilizer but as a forage crop, the legumes are not to be depended upon unless the proper bacteria are present in sufficient number to adequately supply the plant with nitrogen. There is always a possibility that crop failure may be due to the absence of nodule bacteria. The plant may be starving, even with its yellowing leaves bathed in the element which it craves.

True, this is not always the case, for the legume may get nitrogen from the

soil, as do other crops. On very rich soil a fair crop of legumes may be produced even if there are few legume bacteria present. In this case the seemingly satisfactory crop would be making no addition to the wealth of the soil, but instead would diminish it. The only way to judge of the success of a fertilizing crop is by observing the quantity of nodules on the roots.

Soil Inoculation

There follows a natural question. May it not be possible to supply the nitrogen-fixing bacteria to the soil? Yes. That this may be done without difficulty has been conclusively established, both by scientific experiment and by actual practice on the farm. The process is called "soil-inoculation."

In early experimentation bacteria were placed in sterile soil by leaching. In 1887 the inoculation of field-soil was first attempted at Bremen, Germany. The land used was reclaimed swamp which had never produced leguminous vegetation. It was treated by being sown broadcast with soil taken from a legume-bearing field, 350 pounds to the acre. A vigorous growth resulted, whereas similar land not so treated produced only small and yellow plants.

But the use of legume-bearing earth as an inoculating material was found

History of the Pure Culture

to have its disadvantages, as it involved much labor and, too often, the introduction of weeds and plant diseases. Inoculation is now made by means of a pure culture, that is, an uncontaminated growth of one kind of nodule-producing bacteria. This growth is obtained by removing the bacteria from nodules and transferring them to a sterile solution in which they are free to multiply.

Failure of Gelatin As a Medium

Bacterial cultures were first prepared on a commercial scale and sold in Germany in 1896. They, however, proved a disappointment, largely owing to the unsuitable character of the medium in which the bacteria were grown. This medium was a gelatin, already so rich in nitrogen that the growth of the bacteria was discouraged. Also a process called plasmolysis was likely to take place, that is, the medium being denser than the protoplasm of the cell, the moisture of the cell flowed out into the medium, causing the death of the bacteria. Discredit was thus cast upon the use of pure cultures.

Eventually the study of pure-culture methods was undertaken by the United States Department of Agriculture. European methods seemingly having

failed, attempts were made along new lines. The need for this undertaking was particularly felt owing to the introduction into this country of two Asiatic legumes, alfalfa and soy beans. In the first propagation of soy beans it had been found necessary to import humus material from Japan to supply the plants with their characteristic nodule-forming bacteria. Soil for the raising of alfalfa, it was found, could be inoculated with humus from old alfalfa or sweet clover fields. Inoculation by such means, however, always had its disadvantages and a pure-culture method was greatly desired.

The Cotton Culture Good in Theory Only

In 1905 the Bureau of Plant Industry produced the so-called "cotton culture," a method which, it was at first supposed, had solved all difficulties. Pieces of absorbent cotton were moistened in a liquid culture and dried. This cotton was supposed to be placed by the user in a liquid salt which would provide a medium in which the bacteria would rapidly multiply. The method, however, did not work out in practice. There was always danger of contamination of the culture by bacteria and moulds from the air and, moreover, the drying of the cotton had already destroyed a large part of the desired bacteria. Thus such

cultures failed to produce satisfactory results.

Various other methods of distribution have been tried. Notable among these are the dried cultures which were tried out by the U. S. Department of Agriculture and the cultures on "agar" which were used by the Ontario Agricultural College, Guelph, Canada. The latter method gave fairly satisfactory results if the fresh cultures were used. Others evolving the use of liquid or humus as a medium were eventually produced and are used today with a considerable degree of success. A dry medium fails to supply moisture to the bacteria, which, as before stated, is of vital importance. A dry humus is certain to lower the vitality and shorten the life of the bacteria.

Other Methods

The most thoroughly successful method, and one which is now widely and satisfactorily used, was perfected a few years ago. This is the method used exclusively in the preparation of Scott's bacteria. The medium in which the bacteria are colonized is sterilized sand of a very fine texture, to which is added water and various nutrient substances. The advantages of the sand medium is that it absorbs the poisons given off by the bacteria,

Sand the Successful Medium

which, in other types of culture, such as humus and gelatin, accumulate and destroy the bacterial life. Sand permits the growth of more bacteria per ounce and per unit volume than humus and the vitality of the organism is retained for a longer time. If humus is used as a medium the organic content is apt to permit the development of other bacteria and fungi. The sand used is first sterilized by heat, thus rendering it impossible for plant diseases or weeds to be transmitted. This culture, as sold, is efficient during the entire season for which it is made, and even longer.

Superiority of Scott's Culture

The general advantages of Scott's bacteria are that the cultures contain a particularly large number of bacteria, retain their efficiency for a long time and are economical to use. The cultures are sold in packages at one dollar each, postage paid. For all small seeded legumes, one culture suffices for thirty pounds of seed, while for large seeds like soy beans, one culture is sufficient for sixty pounds of seed. If soy beans are planted with corn, one culture is enough for six acres, and the cost of inoculation is less than seventeen cents per acre.

The method of applying the culture to the seed is simple. The seed is first

Method of Application

spread on a clean floor or placed in a tub. The culture is then poured from the container into a clean vessel, one container of water added for clover or vetch, or two for beans or peas, and the culture stirred thoroughly. The mixture is then sprinkled over the seed, which is stirred with the hand or a rake until each seed is slightly moistened. The bacteria will adhere to the seed. When the seed is dry it is sown in the usual way.

The efficiency and value of soil-inoculation with the pure culture has been abundantly demonstrated both by experiment and practical use.

Experiments with soy beans at the New Hampshire Experiment Station in

Results of Some Experiment Station Tests

1917 showed that inoculated seed yielded 7.2 tons green weight per acre, while uninoculated seed yielded only 4.7 tons. In Ohio it was shown that seeds of inoculated plants contained 42.47 per cent protein and the uninoculated only 35.26 per cent protein. Nitrogen is the principal constituent of protein, hence the more nitrogen a plant contains, the richer it is in protein and the more valuable feed. Inoculation causes legumes to have a larger nitrogen content.

At the Canadian Experimental

Farms in 1909 an inoculated field produced per acre 2,560 pounds of cured alfalfa. A similar inoculated field produced 7,200 pounds. At the Alabama Experiment Station an acre of hairy vetch, uninoculated, produced 900 pounds of green forage. A similar acre, inoculated, produced 9,136 pounds. In Minnesota it was found that an acre of uninoculated sweet clover produced 11 pounds of nitrogen per acre, while a similar acre, inoculated, produced 128 pounds.

At the Illinois Experiment Station it was found that the tops of cowpeas which had not been inoculated contained 2.48 per cent of nitrogen, while the inoculated had 4.24 per cent. The inoculated plants contained about twice as much dry matter as the plants not inoculated.

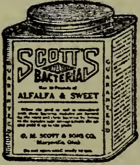
From such experiments it is safe to draw the conclusion:—***It is unwise to attempt to grow leguminous crops for either forage or fertilization without suitably inoculating the soil.***

In addition to this booklet we have published the following which we shall gladly send to individuals, farm bureaus or schools:

Scott's Field Seed Book.
Charts containing Questions and Answers on Sweet Clover, Soy Beans and Bacteria,

Weedless Lawns.

O. M. SCOTT & SONS CO.
Marysville, Ohio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